

NASA Technical Memorandum 103208

# Optical Characterization of Clouds of Fine Liquid-Nitrogen Particles

Robert D. Ingebo  
*Lewis Research Center*  
*Cleveland, Ohio*

(NASA-TM-103208) OPTICAL CHARACTERIZATION  
OF CLOUDS OF FINE LIQUID-NITROGEN PARTICLES  
(NASA) / P USCL 148

N90-26299

Unclass

63/35 0295196

Prepared for the  
21st Annual Meeting of the Fine Particle Society  
San Diego, California, August 21-25, 1990





# OPTICAL CHARACTERIZATION OF CLOUDS OF FINE LIQUID-NITROGEN PARTICLES

Robert D. Ingebo  
National Aeronautics and Space Administration  
Lewis Research Center  
Cleveland, Ohio 44135

## SUMMARY

Characteristic drop size,  $D_{32}$ , of clouds of fine liquid-nitrogen particles was measured with a scattered-light scanning instrument developed at NASA Lewis Research Center. Calibration of the instrument was accomplished with suspensions of monosized polystyrene spheres and the scattered-light scanner was then used to investigate the mechanism of liquid-nitrogen jet disintegration in high velocity gas flow. The Sauter mean diameter,  $D_{32}$ , was found to vary inversely with nitrogen gas mass-flux raised to the 1.33 power. Values of  $D_{32}$  varied from 5 to 25  $\mu\text{m}$  and the mass-flux exponent 1.33 agrees well with theory for liquid jet breakup in high velocity gas flow.

Loss of fine particles due to the high vaporization rate of liquid nitrogen was avoided by sampling the spray 1.3 cm downstream of the nozzle orifice. The presence of high velocity and thermal gradients in the gas phase also made sampling of the particles quite difficult. As a result, it was necessary to correct the measurements for background noise produced by both highly turbulent gas flow and thermally induced density gradients in the gas phase.

## INTRODUCTION

Optical particle-sizing instruments are needed that will overcome the many difficult problems encountered in the study of cryogenic sprays. It is very difficult to obtain reproducible drop size data for very fine liquid-nitrogen particles formed by the disintegration of cryogenic-liquid jets in two-fluid atomizers. One of the most severe measurement problems is the loss of small drops due to their high vaporization rates. Therefore, cryogenic sprays should be sampled very close to the atomizer orifice. In a cryogenic liquid-nitrogen spray, the drops are formed at a temperature very close to their boiling point, i.e., 77 K, which is quite low compared to the atomizing gas temperature of 295 K. This not only makes small drops evaporate very quickly but the temperature gradient in the gas-phase surrounding the drops presents further difficulties. Thermal gradients tend to scatter the laser beam due to large variations in the index of refraction and this produces background noise when light-scattering measurements are being made. To overcome these difficulties, the scattered-light optical particle-sizing instrument described in reference 1 was further developed at NASA Lewis Research Center. Improvements of the instrument are discussed in detail in reference 2 and as a result it was possible in the present study to measure characteristic drop sizes of liquid-nitrogen sprays with the scattered-light scanner.

Several investigators have made experimental measurements of the drop size of water and fuel sprays and correlated it with relative velocity, i.e., gas velocity relative to liquid velocity, and also with liquid properties as

given in references 3 to 7. Some correlations agree and some do not agree very well with atomization theory. This is attributed to the fact that measurement techniques and drop sizing instruments have not yet been developed and standardized to the extent that good agreement might be expected. In the present study, the entire spray cross section was sampled at a distance of  $x = 1.3$  cm downstream of the atomizer orifice, whereas some investigators have used sampling distances on the order of 10 to 20 cm.

#### NOMENCLATURE

$A_o$	atomizer orifice area, $\text{cm}^2$
$D_i$	diameter of $i^{\text{th}}$ drop, cm
$D_{32}$	Sauter mean drop diameter, $\sum n_i D_i^3 / \sum n_i D_i^2$ , cm
$n$	number of droplets
$V$	fluid velocity, cm/sec
$W$	weight flow of fluid, g/sec
$\bar{x}$	axial downstream spray sampling distance, cm
$\rho$	density of fluid, $\text{g/cm}^3$

#### Subscripts

$c$	acoustic
$n$	nitrogen gas

#### APPARATUS AND PROCEDURE

A pneumatic two-fluid nozzle was mounted in the center of the test section as shown in figure 1. A detailed diagram is shown in figure 2 of the two nozzles that were tested with orifice areas of 0.112 and 0.264  $\text{cm}^2$ , respectively. Air supplied at ambient temperature, 293 K, passed through the 24 cm inside diameter test section at a velocity of 5 m/sec to aid in transporting small drops through the laser beam. At a temperature of 77 K measured with an iron-constantan thermocouple, liquid nitrogen,  $\text{LN}_2$ , was axially injected into the air stream at a flow rate of 29 g/sec, as indicated by a turbine flow meter. The atomizing gas, i.e., gaseous nitrogen at 298 K, was admitted into the outer tube and disintegrated the  $\text{LN}_2$  jet along the center line of the atomizer. Nitrogen gas flow rate was varied over a range of 1.3 to 4.5 g/sec as measured with a 0.51 cm diameter sharp-edge orifice.

The optical system of the scattered-light scanner is shown in figure 1. Scattered light is measured as a function of scattering angle by repeatedly sweeping a variable length slit in the focal plane of the collecting lens. The data obtained is scattered-light energy as a function of scattering angle, relative to the laser-beam axis. The method of particle size measurement is similar to that given in reference 2.

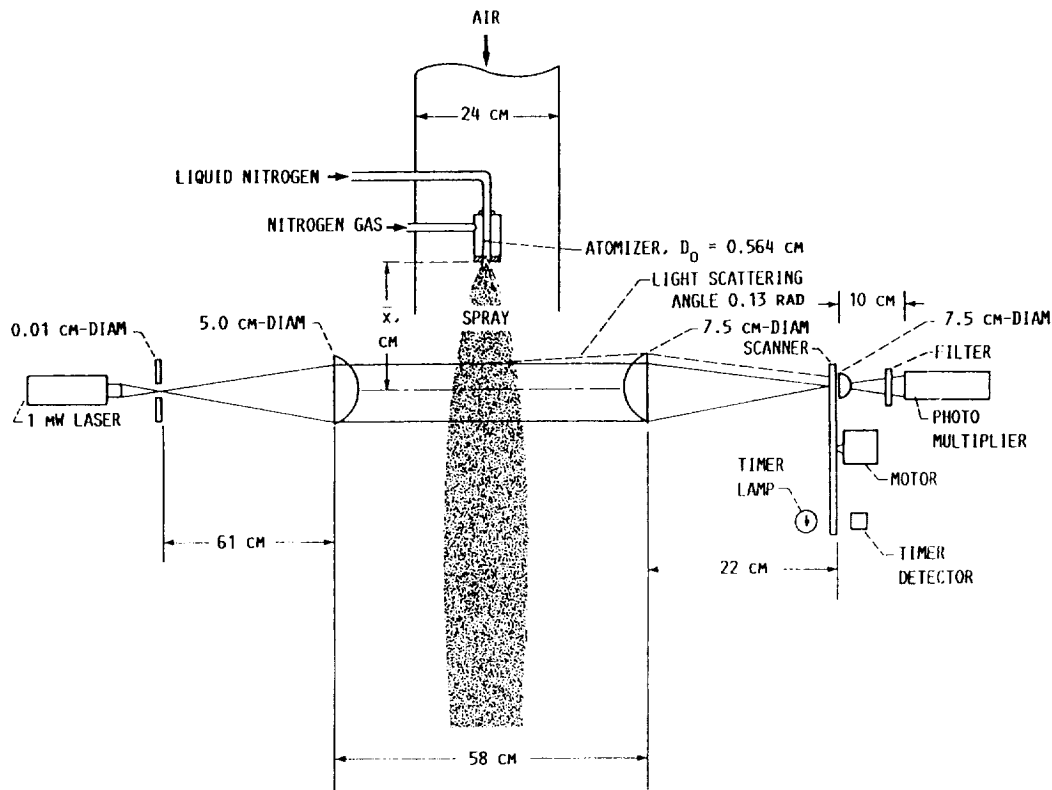


FIGURE 1. - ATMOSPHERIC PRESSURE TEST SECTION AND OPTICAL PATH OF SCATTERED-LIGHT SCANNER.

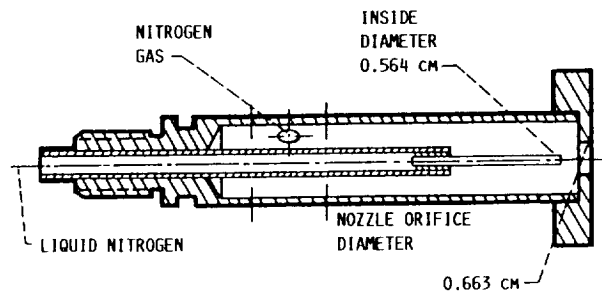


FIGURE 2. - DIAGRAM OF PNEUMATIC TWO-FLUID ATOMIZER.

## EXPERIMENTAL RESULTS

Two pneumatic two-fluid atomizers were used with liquid and gaseous nitrogen to determine the effect of nitrogen-gas flow rate on the characteristic drop size of a cryogenic spray. Also, the effect of gas mass-flux on characteristic drop size was investigated to determine a correlating expression for the two nozzles.

### Effect of Nitrogen Gas Flow Rate on Characteristic Drop Size

The entire spray cross section was sampled at an axial distance of  $x = 1.3$  cm, where  $x$  is the distance from the atomizer orifice to the center line of the laser beam. Liquid nitrogen flow rate was held constant at

29.0 g/sec. Characteristic drop diameter  $D_{32}$ , Sauter mean diameter, was measured for the two atomizers and plotted against nitrogen gas flow rate,  $W_n$ . The following relationship was obtained:  $D_{32}^{-1} \sim W_n^{1.33}$  at a downstream distance of  $x = 1.3$  cm. This expression agrees very well with that given by atomization theory for liquid-jet disintegration in the regime of aerodynamic-stripping, i.e., in high velocity gas streams (ref. 8).

#### Correlation of Nitrogen Gas Mass-Flux with $D_{32}$

Reciprocal Sauter mean diameter,  $D_{32}^{-1}$ , is plotted against atomizing-gas flow rate per unit area,  $W_g/A_o$ , as shown in figure 3. From this plot, the following relationship is obtained:  $D_{32}^{-1} = 58 (W_g/A_o)^{1.33}$ , where 58 is the correlating coefficient for the two nozzles. Also, it should be noted that  $W_g/A_o$  is equal to the gas mass-flux,  $\rho_g V_c$ , where  $\rho_g$  and  $V_c$  are gas density and acoustic velocity, respectively.

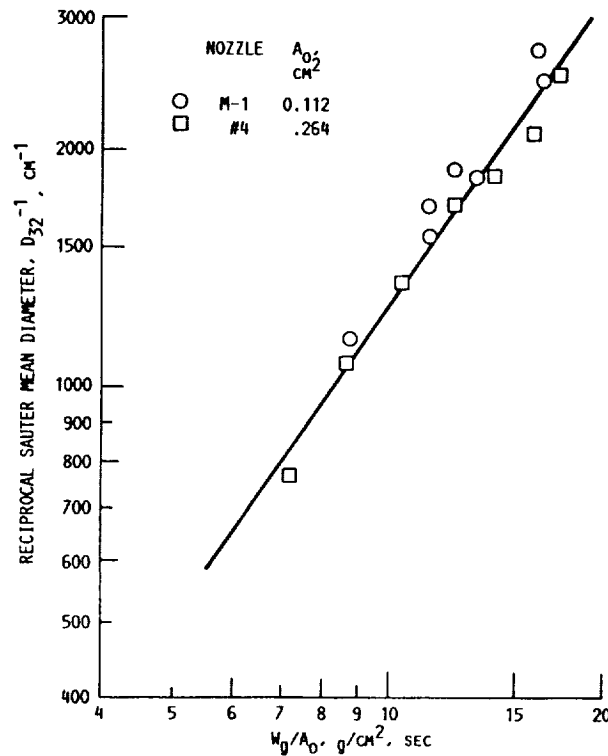


FIGURE 3. - VARIATION OF RECIPROCAL SAUTER MEAN DIAMETER WITH GAS FLOWRATE PER UNIT AREA,  $W_g/A_o$ .

#### REFERENCES

1. Ingebo, R.D.: Experimental and Theoretical Effects of Nitrogen Gas Flow Rate on Liquid-Jet Atomization. J. Propulsion Power, vol. 4, no. 5, Sept.-Oct. 1988, pp. 406-411.
2. Ingebo, R.D.; and Buchele, D.R.: Scattered-Light Scanner Measurements of Cryogenic Liquid-Jet Breakup. NASA TM-102432, 1990.

3. Kim, K.Y.; and Marshall, W.R., Jr.: Drop-Size Distributions from Pneumatic Atomizers. AIChE J., vol. 17, no. 3, May 1971, pp. 575-584.
4. Lorenzetto, G.E.; and Lefebvre, A.H.: Measurements of Drop Size on a Plain-Jet Airblast Atomizer. AIAA J., vol. 15, no. 7, July 1977, pp. 1006-1010.
5. Nukiyama, S.; and Tanasawa, Y.: Experiments on the Atomization of Liquids by Means of an Air Stream, Parts III-IV. Trans. Soc. Mech. Eng. Jpn., vol. 5, no. 18, Feb. 1939, pp. 63-75.
6. Weiss, M.A.; and Worsham, C.H.: Atomization in High Velocity Airstreams. Am. Rocket Soc. J., vol. 29, no. 4, Apr. 1959, pp. 252-259.
7. Wolf, H.E.; and Andersen, W.H.: Aerodynamic Break-up of Liquid Drops. Proceedings of the 5th International Shock Tube Symposium, Z.I. Slawasky, J.F. Moulton, Jr., and W.S. Filler, eds., Naval Ordnance Lab., White Oak, MD, 1965, p. 1145-1169. (Avail. NTIS, AD-638011.)
8. Adelberg, M.: Mean Drop Size Resulting From the Injection of a Liquid Jet Into a High-Speed Gas Stream. AIAA J., vol. 6, no. 6, June 1968, pp. 1143-1147.

# Report Documentation Page

1. Report No. NASA TM-103208		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Optical Characterization of Clouds of Fine Liquid-Nitrogen Particles				5. Report Date	
				6. Performing Organization Code	
7. Author(s) Robert D. Ingebo				8. Performing Organization Report No. E-5616	
				10. Work Unit No. 505-62-21	
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191				11. Contract or Grant No.	
				13. Type of Report and Period Covered Technical Memorandum	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546-0001				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract  Characteristic drop size, $D_{32}$ , of clouds of fine liquid-nitrogen particles was measured with a scattered-light scanning instrument developed at NASA Lewis Research Center. Calibration of the instrument was accomplished with suspensions of monosized polystyrene spheres and the scattered-light scanner was then used to investigate the mechanism of liquid-nitrogen jet disintegration in high velocity gas flow. The Sauter mean diameter, $D_{32}$ , was found to vary inversely with nitrogen gas mass-flux raised to the 1.33 power. Values of $D_{32}$ varied from 5 to 25 $\mu\text{m}$ and the mass-flux exponent 1.33 agrees well with theory for liquid jet breakup in high velocity gas flow. Loss of fine particles due to the high vaporization rate of liquid nitrogen was avoided by sampling the spray 1.3 cm downstream of the nozzle orifice. The presence of high velocity and thermal gradients in the gas phase also made sampling of the particles quite difficult. As a result, it was necessary to correct the measurements for background noise produced by both highly turbulent gas flow and thermally induced density gradients in the gas phase.					
17. Key Words (Suggested by Author(s)) Fine particles; Light scattering; Particle sizing; Characteristic particle size; Cryogenic liquids; Multi-phase flow			18. Distribution Statement Unclassified - Unlimited Subject Category 35		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of pages 6	
				22. Price* A02	